EXPERIMENTAL ANALYSIS ON SURFACE ROUGHNESS OF EN-24 HARDENED STEEL

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CERTIFICATE

This is to certify that the work in this thesis entitled "Experimental analysis on surface roughness of EN-24 hardened steel" by Sambeet Samantaray, has been carried out under my supervision in partial fulfilment of the requirements for the degree of Bachelor of Technology in Mechanical Engineering during session 2014-2015 in the Department of Mechanical Engineering, National Institute of Technology Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

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ABSTRACT

In this thesis, it is about the machining of the EN-24 hardened steel that involves turning operation of the EN-24 with the help of coated carbide insert of ISO designation CNMG 120408. Analysis of the surface roughness is done experimentally with specific input values of feed, depth of cut and speed and gradually the optimal condition is found out. A relation between the inputs and the output is determined and thereafter, the analysis is done how the inputs affected the output. First using the full factorial composite design a layout of the experiment is made after which it is conducted. The profilometer is used to measure the surface roughness. Here the L_{27} Taguchi method is used for the determination of the change in surface roughness with respect to the speed, feed and depth of cut. This can be analysed with help of the contour plots, 3-D surface plots and different graphs produced by the MINTAB 16 software. We can easily determine the effects by visualizing the main effect plots and interaction plots also. With the help of ANOVA (Analysis of Variance), the most effective or the optimal parameters for the output is determined. The regression equations are also obtained. All the parameters are found to be significant in determination of the surface roughness and possible conclusions are made at the end.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The main motive of modern machining industries is to obtain a product of higher reliability or higher quality. Quality as in terms of the workpiece, is with a better surface integrity or with a desired surface finish, the workpiece being dimensionally accurate, thereby increasing the rate of production, on the other hand, decreasing the deteriorating effects on the tool life. It can be also held accountable for decreasing the machining cost. Earlier, hardened steels were machined by grinding operations for they had immense toughness with strength and wear resistant properties. This in turn, consumed more amount of time and the production was limited to certain geometrical specifications only. Recently, the turning process has overtaken the grinding process for the machining of the hardened steels which has led to many advantages including a significant decrease in setup changes, cost of the product and ideal time consumption. Proper and continuous improvement in the quality management process, which may include tool selection and specification, optimum machining parameters like speed (V), feed (F) and depth (D) alongwith tool geometries like rake angle, geometry of the cutting edge, etc. should be considered and taken into account while keeping in mind the quality of the surface finish.

Machining refers to a wide range of processes which transform raw materials into final desired shape and size. Now there are many processes which share a common entelechy as ‘controlled material removal’ and are together termed as subtractive manufacturing. Among these, the three common or principal machining processes are classified as turning, milling and drilling.

Turning is one of the basic metal machining processes which involves a workpiece that rotates and a tool which does not rotate. It can be carried out in traditional lathe machines as well as CNC machines. The former needs manual operation and frequent supervision whereas, the latter is automated.

Quality is of paramount value when it comes to production manufacturing. So, for turning operations keeping quality as the sole consideration, surface roughness becomes the crux of the topic. Surface characteristics have influence or significant effect on properties like fatigue strength, corrosion resistance, creep life, surface friction, lubricant holding capacity, load bearing capacity and so on. So, there is a need for specification of the surface roughness in accordance with the application or purpose.

1.2 OBJECTIVES

The objectives of the project produced in the thesis are as follows:

- To analyze the surface integrity by investigating the surface roughness when ZrCN coated carbide cutting tool is used in trial experiments.
- To develop an experimental design matrix using full factorial DOE (design of experiment) & to conduct the experiments according to Taguchi orthogonal array design.
- To measure the surface roughness of the workpiece.
- To set up mathematical models for surface roughness with best fits with the use of linear regression analysis.
- To confirm that the experiments verify the mathematical models.

1.3 MOTIVATION

By bringing up reforms and continuously improving the performance technologically and efficiently, the economic performance of the machining operations can be enhanced to a newer level. Performance improvements are seen by using tools with more wear resistance properties as well as with new application of tool geometry and specification. Recently, one of such improvements can be found with the use of hard surface coatings like carbide coatings. Hard coatings as TiN, TiC and Al_2O_3 have proved to increase the efficiency of the machining operation by improving the tool life as well as the operable machining speed. These have also proved their significance by showing a decrease in cutting forces as well as power which is due to a lower frictional coefficient between the tool and the workpiece.

The main motive of the machining technology these days is to enhance the tool life as well as its properties and enabling them to work under higher or greater speeds. These are manufactured by powder metallurgy processes. Proper tool material selection holds a key while considering the cost of manufacturing. These all; the factors and parameters mentioned above sum up to determine the quality of the product in every aspect.

CHAPTER 2

LITERATURE REVIEW

In this chapter the reviews of the research works of many authors are cited from various research papers with the needed theory, information and the optimization techniques associated with the turning operation.

A single point cutting tool with a suitable hardness or hardness greater than the workpiece is set in the tool post and it is given a feed in the linear direction along the rotational axis of the job which is rotating to remove the material from its surface. This is the definition of the basic turning operation. The tool is given the feed motion whereas, the job or the workpiece is given a cutting motion.

The specification and the composition of the cutting tool matters to a lot extent on the machining process and the result. In order to withstand a huge amount of force without breakage and deflection due to the hardened workpiece the tool needs to be properly designed. In this prospect, the coated carbide tools having a better withstanding capacity and less tool wear prove to be better than the uncoated ones.

Lalwani et al. [1] carried out hard turning of MDN250 with a coated ceramic tool and investigated the effects of the cutting parameters (speed, feed and depth) on the cutting forces as well as on the surface roughness. The experiments followed or used the RSM (response surface methodology). The results gave an indication that the cutting forces and roughness did not vary much with the cutting speed when in a range of 55–93 m/min.

Davim and Figueira [2] used ceramic cutting tools with a mixed composition of Al_2O_3 and TiC with a ratio of 70% and 30% respectively for the hard turning of a cold work steel, D2. Results showed that the speed and to some extent the cutting time as well, influenced the tool wear.

However, the feed rate and the time became the influential parameters in the case of surface roughness.

Asilturk and Akkus [3] performed turning operation on hardened AISI 4140 with coated carbide inserts with a mixed composition of Al_2O_3 and TiC. He tried to minimize the surface roughness parameters by the use of the Taguchi method. From the results, it was evident that the feed influenced significantly on the parameters. With these, the feed-speed and the depth-speed interactions showed some significance too.

Bhattacharya [4] carried out machining of AISI 1045 steel with high speed. He used the Taguchi design along with, the ANOVA to analyse the effects of the input parameters on the surface finish. The cutting speed was found to be the most significant one among the input parameters.

Benga and Abrao [5] carried out analysis on the effects of the input parameters like speed and feed on the surface roughness of (1000Cr6) bearing steel. He used a three-level factorial design. The tool he used was of CBN (cubic boron nitride). Feed was found to be the most significant factor.

Ozel [6] carried out hard turning operation of AISI H13 steel and analysed the roughness and different forces associated with the cutting operation with the help of ANOVA. According to the results, many parameters marked their influence significantly on the surface roughness. Of them, were the hardness of the workpiece, tool geometry, feed and speed. More precisely, with a lower hardness and a smaller nose the surface roughness was found to increase.

Singh and Rao [7] carried out hard turning of AISI 52100. He used inserts made up of Al_2O_3 and TiCN mixture. According to the results, feed was found to be the most significant one whereas, the nose radius and speed followed it.

Singh et al. [8] carried out turning of EN-24 with tungsten carbide inserts coated with a layer of titanium carbide. His analysis was based on the surface roughness and the tool life. He used the RSM (response surface methodology) to develop the mathematical model for the analysis. The effects were inferred from the plots developed by the mathematical models.

Noordin [9] carried out dry turning of hardened stainless steel with TiAlN coated carbide tool inserts. The interaction factor speed-feed with a low speed-low feed combination proved out to be the efficient one giving the tool life the longest run and the maximum material removal in the experiments. But an increase in the former combination decreased the tool life.

Suresh et al. [10] carried out machining of hardened AISI 4340 steel with CVD (chemical vapour deposition) coated cement carbide inserts. He analysed the effect of the cutting parameters speed, feed and depth on different machining characteristics of which surface roughness was one. Taguchi design and ANOVA were used for the analysis. Multiple linear regressions led to the correlations. It was inferred that the combination of low speed and high speed showed the minimum surface roughness.

Aslan et al. [11] carried out machining of AISI 4140 steel with a lathe with the help of coated ceramic inserts. Al_2O_3 was used to impart wear resistance, as well as hardness properties to the cutting tool. The Taguchi approach was used for developing the model and the analysis was done with the ANOVA (analysis of variance). It was found that with an increase in the speed the surface roughness significantly decreased. Whereas, the surface roughness increased with an increase in the feed rate.

Kacal and Yildirim [12] carried out high speed turning of hardened AISI S1 cold work steel with the help of ceramic as well as CBN cutting tools. They tried to evaluate the machining performance on the basis of machining force, tool wear and surface roughness. ANOVA was used for the analysis of the influencing parameters. CBN inserts performed better than the ceramic inserts. The CBN cutting tools gave the desired results regarding the surface roughness. It was found that the roughness increased with an increase in the feed rate.

Kumar et al. [13] carried out machining of EN-8 with cemented carbide tools. He analysed the effects of the input parameters (speed, feed and depth) on the roughness. He tried to determine or set the relation between them.

Chinchanikar et al. [14] carried out turning of hardened AISI 52100 steel by using PVD coated TiSiN-TiAlN carbide tools. The results showed lower values for roughness when turning was carried out in dry condition. It was also observed that the surface roughness was greatly influenced by the feed and increased when the cutting speed exceeded 150-160 m/min.

CHAPTER 3

THEORITICAL STUDY

3.1 Turning operation

Turning is one of the most common material removal process. The cutting tool used is a single point cutting tool. The tool should possess a suitable hardness or hardness greater than the workpiece. It is fixed to the tool post and a feed is given to it, to move along a rotating workpiece and remove material from the workpiece. This is the definition of the basic turning operation. The tool is given the feed motion whereas, the job or the workpiece is given a cutting motion. Surfaces of revolution are generally produced by this operation though the flat surfaces are produced by face turning. Turning operations are carried out in lathes and CNC. The former needs manual operation and frequent supervision whereas, the latter is automated. Fig. 3.1 depicts the turning operation.

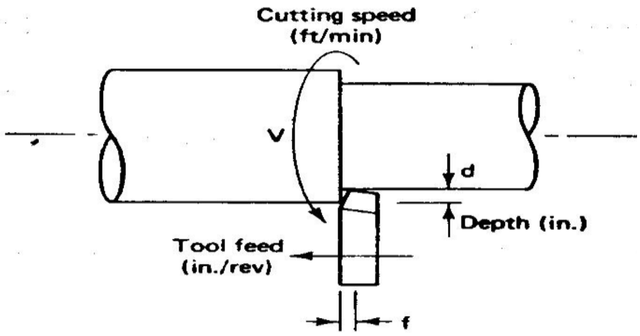


Fig. 3.1 Turning operation

3.2 Cutting tool

In turning operations, a cutting tool is a single point cutting tool which is used for material removal with a linear feed motion and is fixed to the tool post. Generally it should have a greater hardness than the workpiece, as well as certain characteristics like hot hardness, toughness and wear resistance. In Fig. 3.2 some cutting tools are shown.

In all machining operations cutting speed and feed are determined by the type of material the tool is made up of. So, speeds and feeds must be kept at an optimum level to ascertain for an acceptable tool life. To maintain the aforesaid, the cutting tool materials should possess some of the following properties:

- High hardness for easy penetration into the workpiece.
- High mechanical resistance to bending and compression so that it can withstand cutting forces.
- Resistance to abrasion, diffusion and plastic deformation.
- Resistance to high temperature which would otherwise diminish the qualities enumerated above.

Fig. 3.2 Cutting tools

3.3 Coated tool materials

To have a better surface strength and/or a reduction in the chip-tool interface friction coatings are applied. Developments in the past years have led to the possibility of machining of hardened materials. Production of materials or components in hardened state has many advantages like reduction in the machining costs for production, reduction in the number of necessary machine tools required for machining a job, improvement in the surface texture and the surface integrity, a reduction in the number of finishing operations as required and an absence of distortion in parts which are initially caused by heat treatment.

The improvement of coating techniques, with the chemical vapour deposition (CVD) and physical vapour deposition (PVD) on carbide tools enhanced the cutting operation and showed an increase in the efficiency of the machining with the advent of TiN coated tools in the early 1980's. For this reason, this field gained enormous response and researchers were interested in carrying out research works on coated tool materials. TiN coatings proved to be the best with magnificent performance.

Typical coating material includes TiN, TiC, TiCN, Al_2O_3, etc.. Generally in the thickness range of 2-10 µm, these coatings are applied on tools and inserts by chemical vapour deposition (CVD) and physical vapour deposition (PVD) on cemented carbide tools. The CVD process is the most commonly used coating application method for carbide tools with multiphase and ceramic coatings. The PVD coated carbides with TiN coatings, on the other hand, have higher cutting-edge strength, lower friction, lower tendency to form a built-up edge, and are smother and more uniform in thickness, which is generally in the range of 2-4 µm. a more recent technology, particularly for multiphase coating is medium-temperature chemical vapour deposition (MTCVD); it provides a higher resistance to crack propagation than CVD coatings.

The coatings should possess some of the following properties:

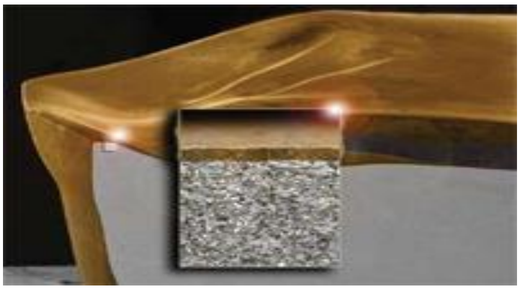
- Higher hardness at higher temperatures.
- Chemical stability and no affinity for the workpiece material
- Low thermal conductivity
- Better bonding with the substrate to prevent flanking
- Little porosity

The effectiveness of coatings, in turning is favoured by the enhancement of properties like hardness, toughness, and high thermal conductivity.

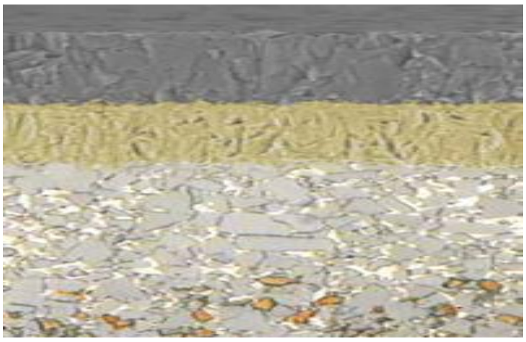
The substrate plays a major role in imparting toughness to the tool whereas, it is the coating which helps in the wear resisting property as well as increasing the hardness of the tool. Coating provides a good abrasion resistance and acts as a thermal and chemical barrier between the tool and the job and increases the tool life. They prove quite impressive, by enhancing the properties of the tool at higher temperatures by imparting resistance to wear due to diffusion, resistance to wear due to oxidation and a superior hot hardness. These also provide with good lubricating properties which help in minimizing the friction between the chip and the tool; the tool and the job interfaces. These also help in lowering the forces associated with the machining process. The advantages go on adding as these coatings help in the chip control mechanism and reduce

the tool's adherence with the job material (the reason for built-up edge formation) thus, providing for a better surface finish.

Coated inserts reduce the frequency of tool indexing or changing and in return increase savings in down time and cost. With the expensive machining tools in use today, this has a big effect in reducing production costs. Simply stated, coating reduces the cost and increases the efficiency. Below mentioned are some coated inserts shown in Fig. 3.3



CVD coating



PVD coating

Fig. 3.3 Coated tool materials

3.4 Tool wear

Due to constant interaction between the tool and workpiece in turning operations, there is a very high rate of friction at the interface which ultimately results in tool wear. Tool wear causes the tool to lose its original shape. At some point of time, the tool ceases to cut efficiently or even fails completely. After a certain degree of wear, the tool has to be re-sharpened or replaced for further use.

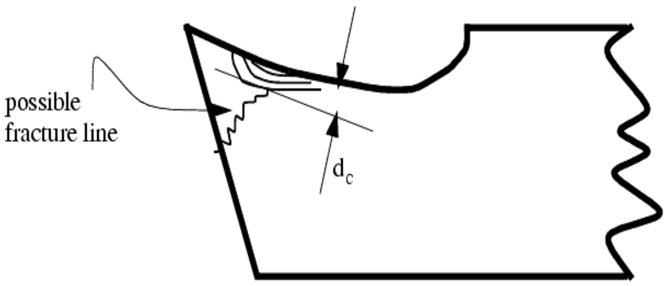
Some general effects on machining operations due to tool wear include:

- increased cutting temperatures
- decreased accuracy of finished part
- poor surface finish
- increased cutting forces

Generally two types of major wears are found in the cutting tools namely; the crater wear and the flank wear.

3.4.1 Crater wear

Crater wear is formed on the rake surface of the tool and it begins at a distance from the cutting edge. This form of wear is due to the intimate contact and pressure of the flowing hot chips. Crater wear is signified by the maximum depth of the crater and the width of the crater formed. The change in length of the crater form is negligible for a particular depth of cut in machining. Crater wear is restricted to chip-tool contact area. As the crater depth increases, the crater front becomes small. As the crater progresses towards the cutting edge followed by the flank wear, the cutting edge becomes weaker and may lead on to chipping of the cutting edge. Thus, crater is often used as an important factor for finding the tool life. Fig. 3.4 depicts the crater wear.



where,

d_c = crater depth

Fig. 3.4 Crater wear

3.4.2 Flank wear

The wear created on the flank or the relief surface is known as the flank wear and it results in the formation of a wear land. Wear land formation is not always uniform along the major and minor cutting edges of the tool. Flank wear most commonly results from abrasive wear of the cutting edge against the machined surface. Flank wear can be checked by examining the tool or by tracking the change in size of the tool or machined part. Fig. 3.5 depicts the flank wear region.

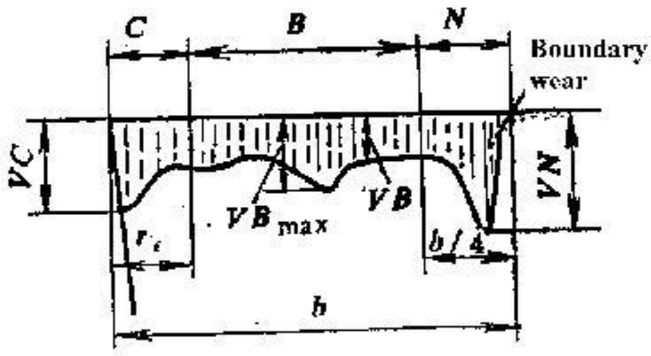


Fig. 3.5 Flank wear region

3.5 Surface roughness

The accuracy of the product according to the specifications and dimensions intended determine the surface quality. The machining operations leave an evidence (characteristic) of their own. These in the form of irregularities at microscopic level on the surface that is machined. These can be identified as patterns, which are distinctive as of the tools used. These patterns are otherwise known as surface roughness. Roughness is a measure of the surface texture. It is calculated by the vertical deviations of a surface (machined one) differing from the ideal surface (not machined one). If these are found to be excessive then it indicates the surface is rough; if found to be small then it indicates that the surface is smooth.

A surface can be characterized by its topography and microstructure. Generally its micro-geometrical properties or texture describes in terms of roughness, waviness and lay and the later by the depth and nature of the altered material zone (AMZ) just below the surface.

Surface roughness is mostly unwanted and undesirable. But the cost of manufacturing increases quite significantly when we try to decrease the surface roughness or keep it within a range. This often results in a trade-off between the manufacturing cost of a component and its performance in application. Formation of micro-cracks, unwanted microstructure changes and residual stress caused by plastic deformation and localized heating in the AMZ can cause premature failure of a component during service. Surface integrity of a component can be defined as the degree of the soundness, wholeness or unimpairedness of the surface topography and microstructure as a result of a given manufacturing operation.

3.5.1 Elements of surface roughness

The elements of the surface roughness are defined as follows:

- **Surface texture** is defined as the variation in terms of roughness, lay, flaws and waviness.
- **Roughness** can be defined as the vertical deviations of the actual surface with reference to an ideal surface.
- **Roughness Height** is defined as the deviation from the mean plane of the machined surface (micrometers). The average of the deviations is taken.
- **Roughness Width** is defined as the width between two successive peak and valley of the roughness.
- **Roughness width cutoff** is the largest spacing of irregularities including average roughness height.
- **Waviness** is defined as the widely spaced variation exceeding the roughness width cutoff. It is assumed that the roughness is superimposed on a surface that is wavy in nature.
- **Waviness height** is defined as the crest to trough height difference of the waves.
- **Waviness width** is defined as the wave length i.e. the distance within successive crests and troughs.
- **Lay** can be defined as the orientation of the surface pattern.
- **Flaws** as the name suggests are the defects, or irregularities, that occur over the surface. These can be in the form of ridges, cracks, scratches, etc..

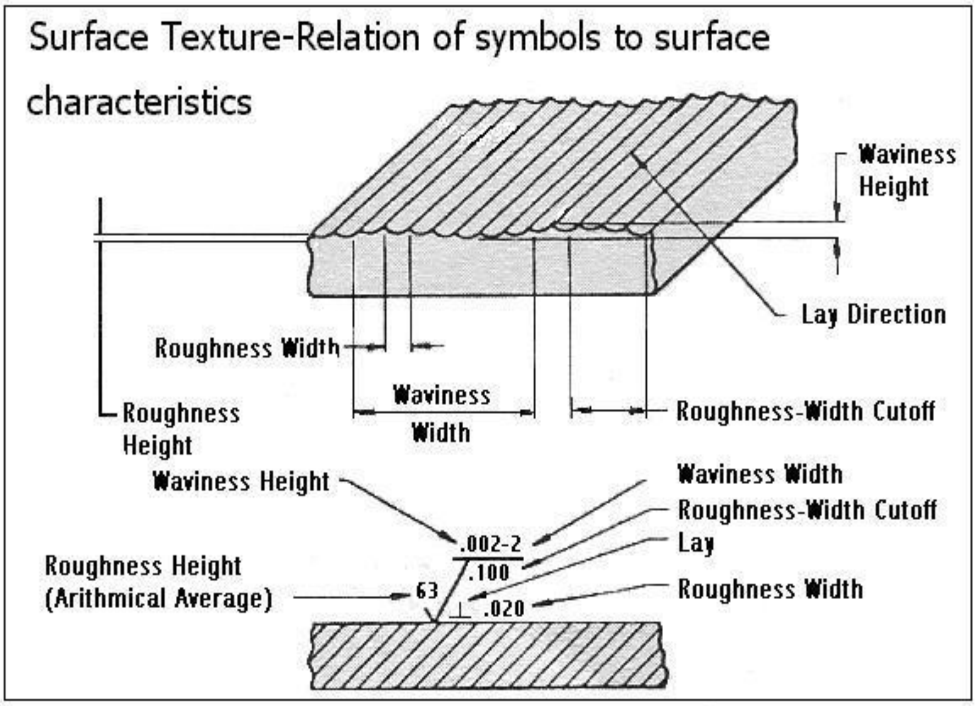
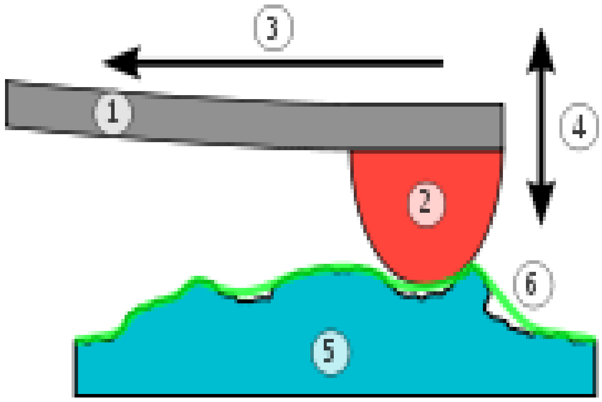


Fig. 3.6 Surface Texture Characteristics

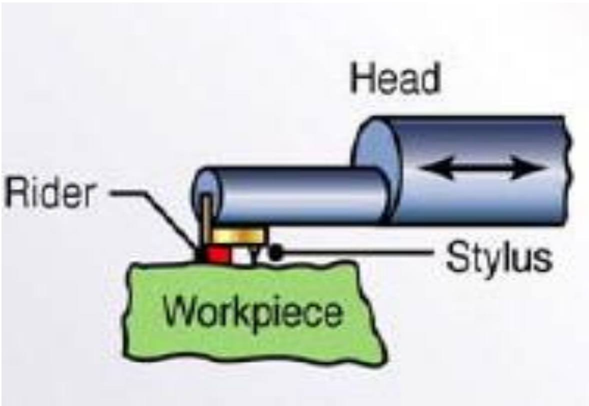
Fig.3.6 shows the different surface texture characteristics.

3.5.2 Measurement of surface roughness

There are mainly two types of methods with which the roughness can be measured. These are classified as contact and non-contact methods. Contact methods as we know, involves the contact between the measuring instrument and the surface. This is done with the help of a stylus which is dragged across the surface to measure the deviations. Profilometers are one of these instruments. Non-contact methods include: Interferometry, Confocal microscopy, Focus variation, Structured light and Electrical capacitance.



(a)



(b)

Fig. 3.7 (i) Stylus probe movement over wavy formed surface

Principle of a contacting stylus instrument; profilometer with reference to Fig. 3.7 (i and ii): A cantilever (1) is holding a small tip (2) that is sliding along the horizontal direction (3) over the object's surface (5). Following the profile the cantilever is moving vertically (4). The vertical position is recorded as the measured profile (6) shown in light green.

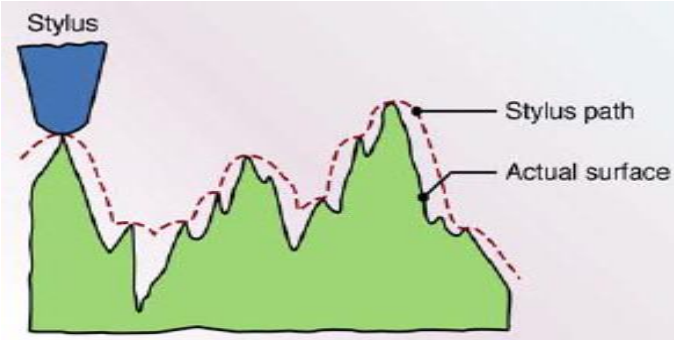


Fig. 3.7 (ii) Stylus probe movement from highest peak to lowest valley in measured length

3.5.3 Parameters for surface roughness

Table 3.1 Various Surface Roughness Parameters

Parameter	Description	Formula
R_a, R_{aa}, R_{yni}	Arithmetic average of absolute values	$R_a = \frac{1}{n}\sum_{i=1}^{n} \lvert y_i \rvert$
R_q, R_{RMS}	Root mean squared	$R_q = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2}$
R_v	Maximum valley depth	$R_v = \min_i y_i$
R_p	Maximum peak height	$R_p = \max_i y_i$
R_t	Maximum Height of the Profile	$R_t = R_p - R_v$
R_{sk}	Skewness	$R_{sk} = \frac{1}{nR_q^3}\sum_{i=1}^{n} y_i^3$
R_{ku}	Kurtosis	$R_{ku} = \frac{1}{nR_q^4}\sum_{i=1}^{n} y_i^4$
R_{zDIN}, R_{tm}	Average distance between the highest peak and lowest valley in each sampling length.	$R_{zDIN} = \frac{1}{s}\sum_{i=1}^{s} R_{ti}$, where s is the number of sampling lengths, and R_{ti} is R_t for the i^{th} sampling length.
R_{zJIS}	Japanese Industrial Standard for R_z, based on the five highest peaks and lowest valleys over the entire sampling length.	$R_{zJIS} = \frac{1}{5}\sum_{i=1}^{5} R_{pi} - R_{vi}$, where R_{pi} R_{vi} are the i^{th} highest peak, and lowest valley respectively.

Table 3.1 describes the different surface roughness parameters.

3.5.4 Factors affecting the surface roughness

The quality of the parts or surfaces that come in contact during machining operation determine the wear and the resulting overall performance. The specifications and orientations of these irregularities formed on the surface of the job depend upon a number of factors such as:

- The *machining variables* like,
  - Speed
  - Feed, and
  - Depth of cut.

- The *tool geometry*,
  - Nose radius
  - Rake angle
  - Side cutting edge angle, and
  - Cutting edge.
- Extent of adherence of the job and the tool and their material properties.
- The quality of the cutting tool.
- Auxiliary tooling, and lubricant.
- Disturbance created in the form of vibrations between the tool and the job**.**

3.6 Design of Experiments

3.6.1 Taguchi method

It is a very renowned quality improvement tool. A Taguchi design , or an orthogonal array, is a method of designing experiments that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor. He developed the methodology and applied them through the factorial designs of the experiments. For many years this method has been implied in manufacturing sector.

Taguchi lays the concepts with regard to his methodology as:

- Quality should be designed rather inspected.
- Minimizing the deviation helps in achieving the best quality.
- The cost of quality is a function of the deviation.

Taguchi commends for a desirable quality of product a process is required which includes design of the system, design of the parameter and design of the tolerance. The results provide with the best or optimum condition for machining for which the surface roughness is the minimum. In this condition, the influence of the uncontrollable factors is the least which results in minimum variation. Orthogonal arrays, variance and signal to noise analysis are the essential tools of parameter design.

3.6.2 Regression analysis

Regression analysis tries to frame a linear relation with a best possible straight line, between the Y variable which is treated as the variation in the outcome and the X variable which is treated as variation in a predictor. After it creates a relation between these two variables the following equation comes into use:

$$Y = b_0 + b_1 X$$

Now for predicting the outcome (Y variable), for different input parameters (X variable) multiple regression analysis is used which is a technique that forecasts an outcome for an input on the basis of other variables. There will be many situations, where the outcome will depend on more than one input variable.

In psychology, many researchers put multiple regression in this way: the ‘independent’ (input) variables which tend to influence other ‘dependent’ (output) variables. Human behaviour in a similar way has many ‘independent’ variables for which it is quite difficult almost impossible to predict the accurate outcomes.

CHAPTER 4

EXPERIMENTAL DETAILS

4.1 Work-piece material

EN-24 equivalent to AISI 4340 (high strength) steel test samples of dimensions ø60×*120*mm is used for the experiment. EN-24 steel has a greater hardness for which it is quite difficult to machine it. It has a higher tendency for strain hardening. It also has a low specific heat. AISI 4340 is a low alloy steel composed of chromium (Cr), molybdenum (Mo) and nickel (Ni) with significant amount and also has silicon (Si), manganese (Mn) in less amounts. It is a heat treatable alloy steel. EN-24 is an equivalent of the AISI 4340. EN-24 possesses higher tensile strength. For this reason it finds its major application in the automotive as well as the aeronautics industries. It is used in making of shafts, axles, couplings, arbors, etc.. Axles and spline shafts are made with this material and turning is the major process. It can take care of shock loads as core is soft but does not wear out as skin is hard. High tensile steel EN-24 is suitable for pump shafts and turbine rotors in general and for similar uses.

Fig. 4.1 EN-24 Steel

4.1.1 Chemical composition of EN-24

Table 4.1. Chemical composition of EN-24 steel in percentage (%)

C	Mn	Cr	Mo	Ni	Si	Fe
0.39	0.77	1.1	0.17	1.55	0.38	Balance

Chemical composition is shown in the above Table 4.1.

4.2 Insert material

A coated carbide insert was used for the experiment. It is CNMG 120408 type of insert.

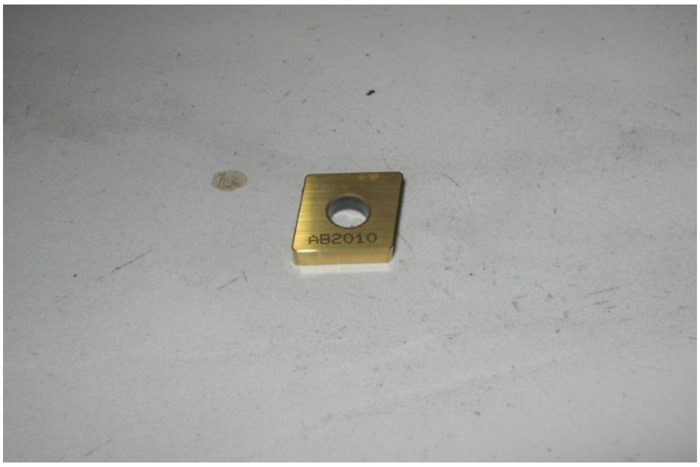


Fig. 4.2 CVD Multilayer coated carbide insert (CNMG120408).

4.3 Experimental setup and procedure

4.3.1 Lathe

The experiment was carried out with a lathe machine in the central work shop. 3 jaw chucks of the lathe held the job quite rigidly. Centre drilling was done to hold the job rigidly in fixed position. The experiment was carried out in dry condition without using cutting fluid. Fig. 4.3 shows the lathe machine:

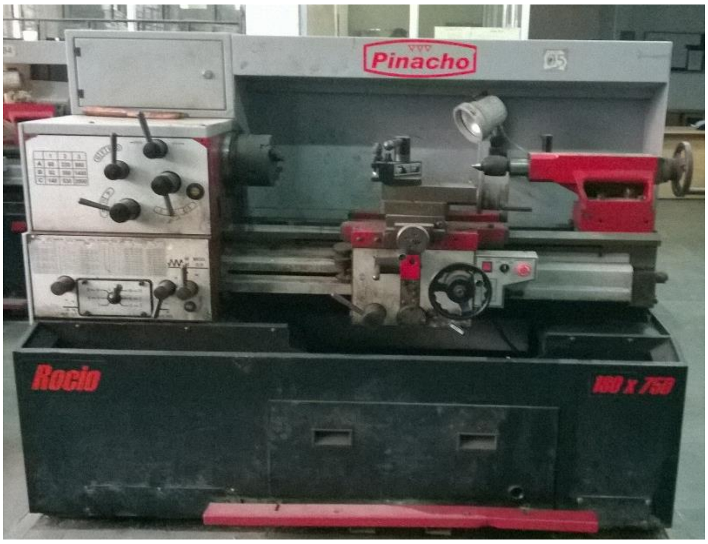


Fig. 4.3 Lathe Machine

4.4. Cutting condition

Workpiece	Hardened EN-24 (AISI 4340) steel
Hardness	47±1 HRC
Cutting speed level (v) in m/min	90, 120, 150
Feed rate level (f) in mm/rev	0.10, 0.15, 0.20
Depth of cut level (d) in mm	0.3, 0.4, 0.5
Coolant condition	Dry turning
Cutting inserts	CVD-ZrCN coated carbide

4.5 Measurement of surface roughness

The surface roughness parameter (R_a) is used for the analysis of surface roughness in the experiment. It is also called the arithmetic average (AA) or the centreline average (CLA). It is the arithmetic mean of the deviations produced on the surface and are referred from the mean line. Graphically, it is shown in Fig.4.4 where the area between the curves divided by the length 'L' is the average roughness. The other roughness parameters were R_z & R_t. R_z is the maximum peak to valley height of the profile within a sampling length. When more than one sampling length is analysed, R_z is the mean value of the individual R_z values for each sampling length. R_t is the maximum peak to valley height of the profile in the assessment (evaluation) length.

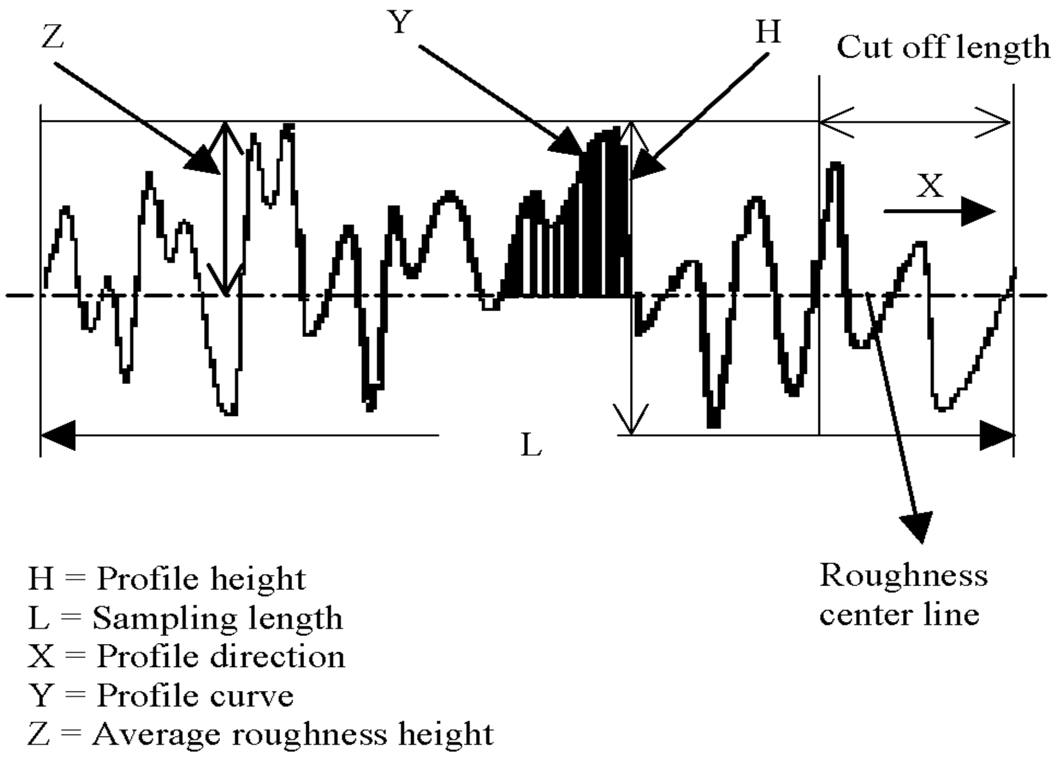


Fig. 4.4 Surface Roughness Profile

4.6 Experimental layout

The experiment was carried out developing an experimental layout and then analysing the effects of the input parameters on the output. The input parameters being speed, feed and depth; and the output being the surface roughness (R_a and R_z). The experiments had three parameters at three levels each, as shown in the Table 4.2 below and experiments were conducted according to Taguchi's L_{27} (3^3) Orthogonal array with 26 degree of freedom.

Table 4.2. Machining parameters and levels

Parameters	Unit	Levels		
		1	2	3
Depth of Cut (D)	Mm	0.3	0.4	0.5
Feed (F)	mm/rev	0.1	0.15	0.2
Cutting speed(V)	m/min	90	120	150

CHAPTER 5

RESULTS AND DISCUSSIONS

The experiment was conducted with a plan developed to analyse the effects of input parameters speed (V), feed (F) and depth (D) on the surface roughness parameters (R_a and R_z). Table 5.1 shows the results of the experiments. Test no. 12 gave the minimum values and test no.16 gave the maximum values for R_a and R_z.

Table 5.1. Orthogonal array L_{27} of Taguchi experiment design and experimental results

Test No.	V	F	D	Ra(μm)	Rz(μm)
1	90	0.1	0.3	0.9	4.83
2	120	0.1	0.3	0.75	4.78
3	150	0.1	0.3	0.52	2.53
4	90	0.15	0.3	1.82	7.37
5	120	0.15	0.3	1.47	6.52
6	150	0.15	0.3	1.32	6.38
7	90	0.2	0.3	1.92	8.62
8	120	0.2	0.3	1.57	6.83
9	150	0.2	0.3	1.40	6.81
10	90	0.1	0.4	0.63	2.83
11	120	0.1	0.4	0.61	2.61
12	150	0.1	0.4	0.44	1.83
13	90	0.15	0.4	1.42	5.43
14	120	0.15	0.4	1.05	4.52
15	150	0.15	0.4	0.85	3.96
16	90	0.2	0.4	2.38	9.12
17	120	0.2	0.4	1.51	6.13
18	150	0.2	0.4	0.81	4.08
19	90	0.1	0.5	0.84	3.98
20	120	0.1	0.5	0.62	3.33
21	150	0.1	0.5	0.61	3.28
22	90	0.15	0.5	1.25	5.48
23	120	0.15	0.5	1.18	4.68
24	150	0.15	0.5	0.72	3.61
25	90	0.2	0.5	1.83	6.82
26	120	0.2	0.5	1.64	7.22
27	150	0.2	0.5	0.76	3.47

5.1 ANOVA (analysis of variance)

ANOVA analysed the results of the experiments and was used to know the significant factors. The results of the ANOVA with surface roughness Ra and Rz are shown in Tables 5.2 and 5.3 respectively. The significance level of α=0.05, i.e. for a confidence level of 95%. The sources which are having a P-value less than 0.05 can be said as the significant parameters.

Table 5.2 Analysis of variance for surface roughness (Ra)

Source	DOF	SS	MS	F-value	P
V	2	1.72614	0.86307	90.00	0.000
F	2	3.58356	1.79178	186.84	0.000
D	2	0.32676	0.16338	17.04	0.001
V×F	4	0.48810	0.12203	12.72	0.002
V×D	4	0.11770	0.02943	3.07	0.083
F×D	4	0.22315	0.05579	5.82	0.017
Error	8	0.07672	0.00959		
Total	26	6.54214			

S = 0.09793 R-Sq = 98.8% R-Sq (adj) = 96.2%

Table 5.3 Analysis of variance for surface roughness (Rz)

Source	DOF	SS	MS	F-value	P
V	2	19.263	9.6315	48.32	0.000
F	2	47.837	23.9183	120.00	0.000
D	2	13.594	6.7971	34.10	0.000
V×F	4	4.324	1.0810	5.42	0.021
V×D	4	1.199	0.2998	1.50	0.288
F×D	4	3.569	0.8923	4.48	0.034
Error	8	1.595	0.1993		
Total	26	91.381			

DOF= Degree of freedom, SS= Sum of squares, MS= Mean squares

S = 0.4464 R-Sq = 98.3% R-Sq(adj) = 94.3%

Table 5.2 presents ANOVA results for R_a. From the results, we can infer that the speed and feed were significant parameters with P = 0.000 followed by depth of cut with P = 0.001 on surface roughness, R_a. The interactions (F×D) and (V×F) are also statistically significant but (V×D) is not statistically significant. Respectively, their P-values were 0.017, 0.002 and 0.083.

Table 5.3 presents ANOVA results for surface roughness, R_z. From the results, we can infer that three of the parameters i.e., speed, feed and depth were found to be significant with P = 0. The interactions (V×F), (F×D) are found to be significant with a P-value of 0.021 and 0.034 respectively and (V×D) is not significant with a P = 0.288 which is greater than 0.05.

5.2 Interpretation of plots

More analysing was done by the interpretation of some plots. These plots included surface plots, contour plots and main effects plots. The plots were given and analysed by the 'MINITAB16' software and are shown in the coming sections from figures- Fig. 5.1 to Fig. 5.8.

Fig. 5.1 shows the main effects plot for surface roughness, R_a. The x axis contains the source or the input parameters otherwise known as the process parameters and the y axis contains the output parameter otherwise known as the response parameter. Some conclusions were drawn from these graphs which helped to determine the optimal conditions. However, the graphs indicated that a feed at 0.10 mm/rev, depth at 0.5mm and a speed at 150m/min were found to be favourable.

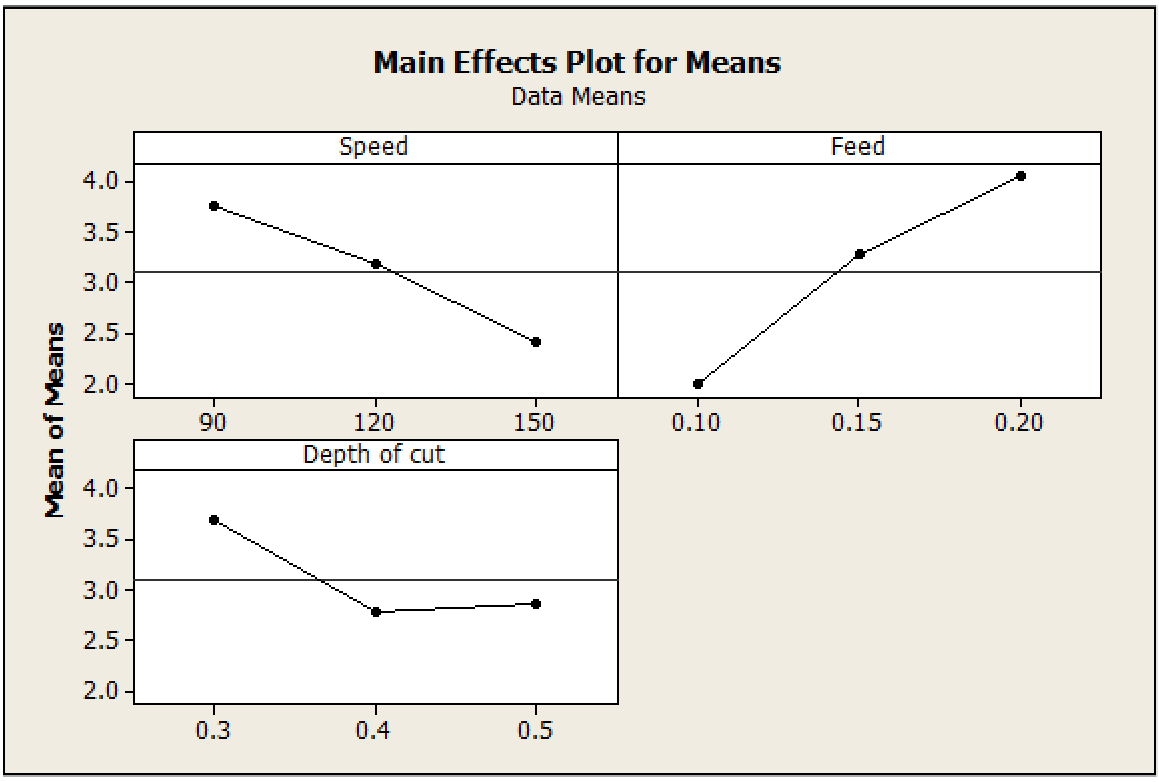


Fig. 5.1 Main effects plot for surface roughness (Ra)

Fig. 5.2 represents the main effects plot for surface roughness, R_z. An increase in the surface roughness was marked with an increase in the rate of feed. Further, the surface finish was found to improve with an increasing speed. The plot indicated that a cutting speed at 150m/min, a depth at 0.4mm and a feed rate at 0.10mm/rev was found to be favourable.

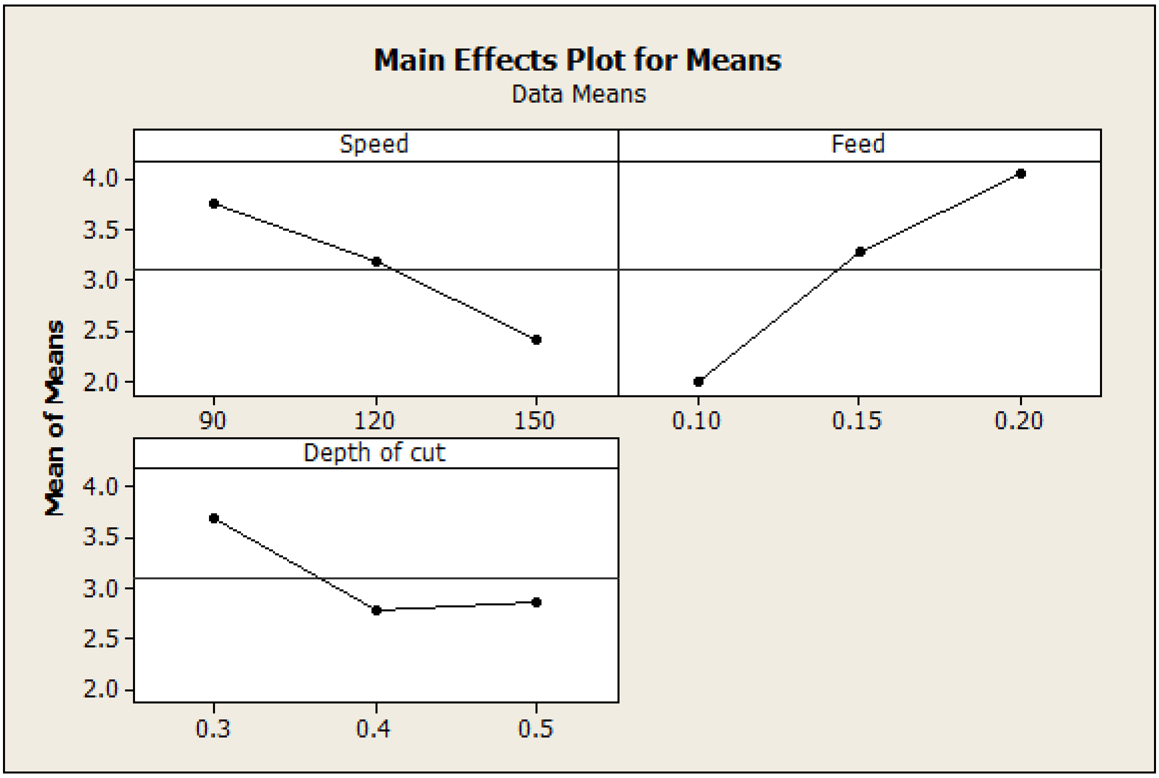


Fig. 5.2 Main effects plot for surface roughness (Rz)

5.3 Correlation

Multiple linear order regression model have been implemented at a confidence level of 95% to obtain the correlation between the machining parameters (speed, feed and depth) and the measured surface roughness parameters, R_a and R_z. The obtained correlation equations were as follows:

$$R_a = -1.97759 + 0.0143241\,V + 28.3889\,F + 1.66389\,D - 0.131667\,V{*}F - 0.0122222\,V{*}D - 9.5\,F{*}D \qquad (R^2=91.44\%)$$

$$R_z = -3.27519 + 0.0263148\,V + 94.9111\,F + 3.55833\,D - 0.344444\,V{*}F - 0.0225\,V{*}D - 53.1667\,F{*}D \qquad (R^2=86.80\%)$$

The influence of machining parameters and their interaction effects on the roughness can be analyzed by using 3D surface plots. Fig. 5.3 and Fig.5.4 show the 3D surface plots for R_a and R_z respectively. For all roughness parameters (Ra and Rz) it is apparent that they seriously increase when the feed increases and decrease speed increases, whilst the depth has a rather neglegible influence for increase of Ra.

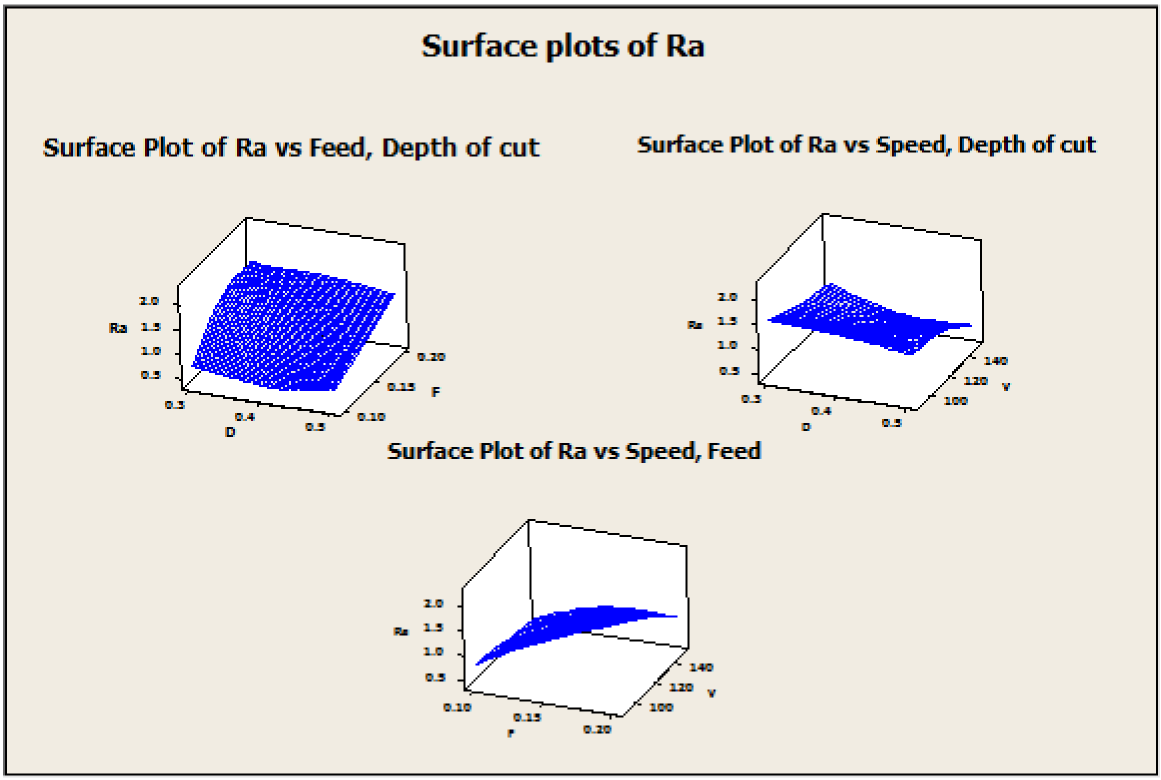


Fig.5.3 3D Surface plots of surface roughness (Ra) versus D, F and V

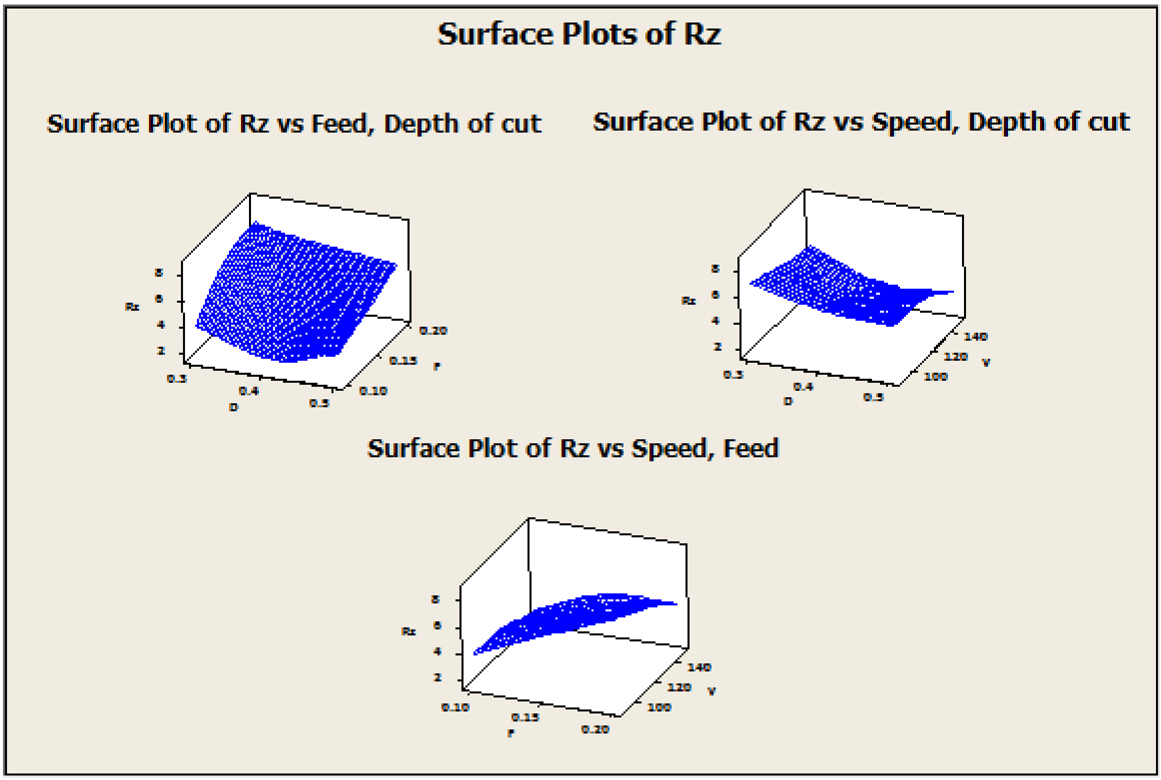


Fig. 5.4 3D Surface plots of surface roughness (Rz) versus D, F and V

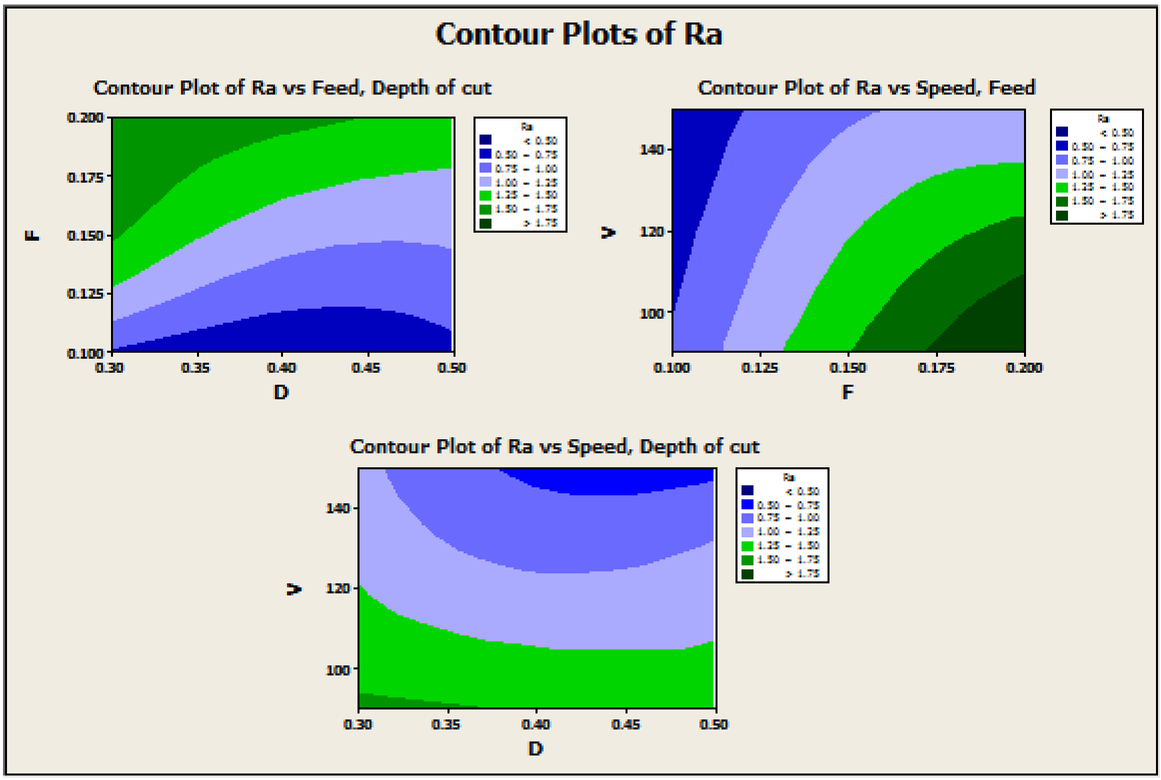


Fig.5.5 Contour plots of surface roughness (Ra)

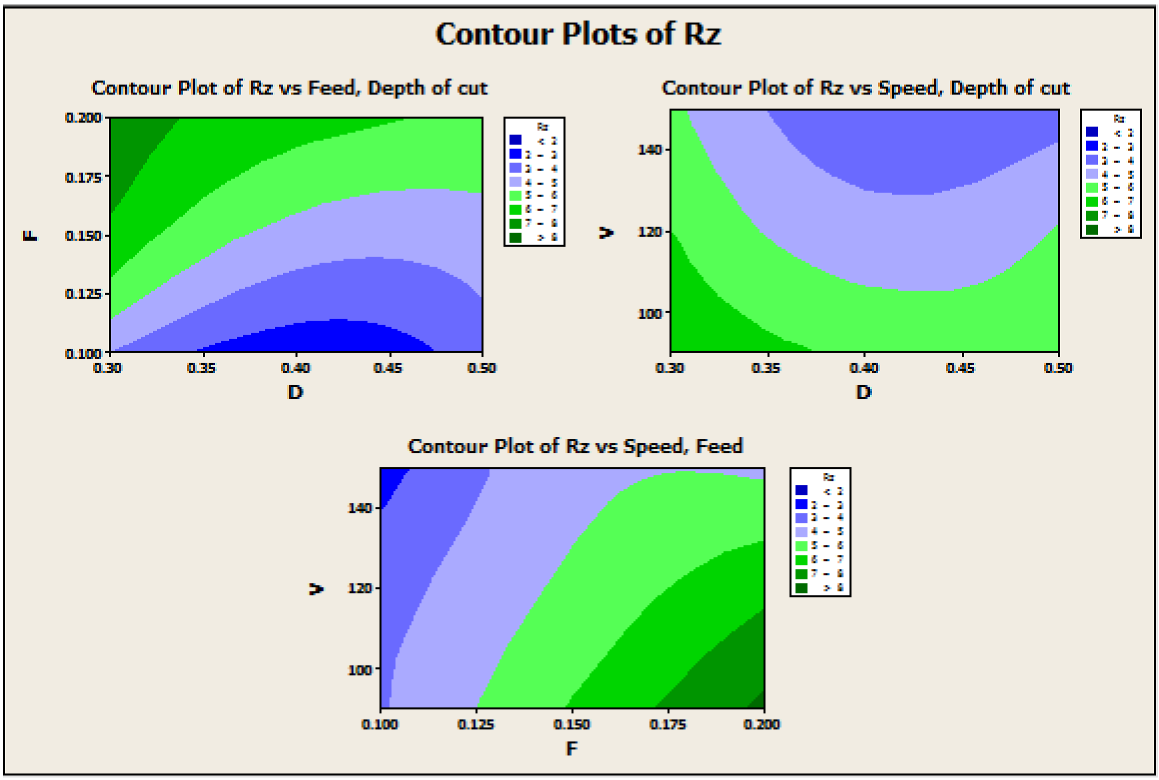


Fig. 5.6 Contour plots of surface roughness (Rz)

Fig. 5.5 and Fig. 5.6 show the contour plots of the interactions of (D×F), (F×V) and (D×V) for R_a and R_z respectively. These plots can help to predict the values for roughness at any point. These plots also show the same results as the 3D surface plots in Fig. 5.3 and 5.4 respectively.

For us to know whether the model is statistical valid or not, we carried out inspection of some plots. The residuals could be said to follow a straight line in normal plot of residuals implying that the errors were distributed normally, shown in Fig. 5.7 and Fig. 5.8 for roughness parameters R_a and R_z respectively. From figure it can be concluded that all the values are within the confidence interval level of 95%. Hence, these values yield better results in future prediction. Fig. 5.7 and 5.8 indicated there is no obvious pattern and unusual structure present in the data which implies that the residual analysis does not indicate any model inadequacy.

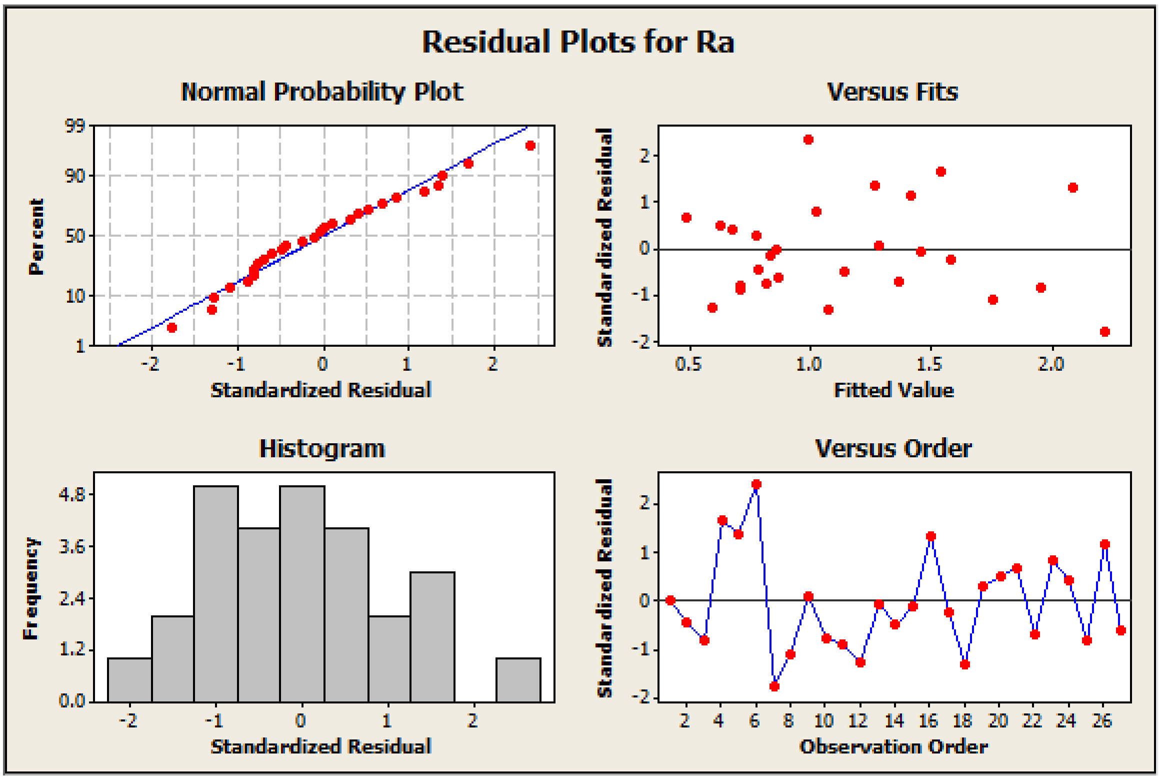


Fig. 5.7 Residual plots for surface roughness (Ra)

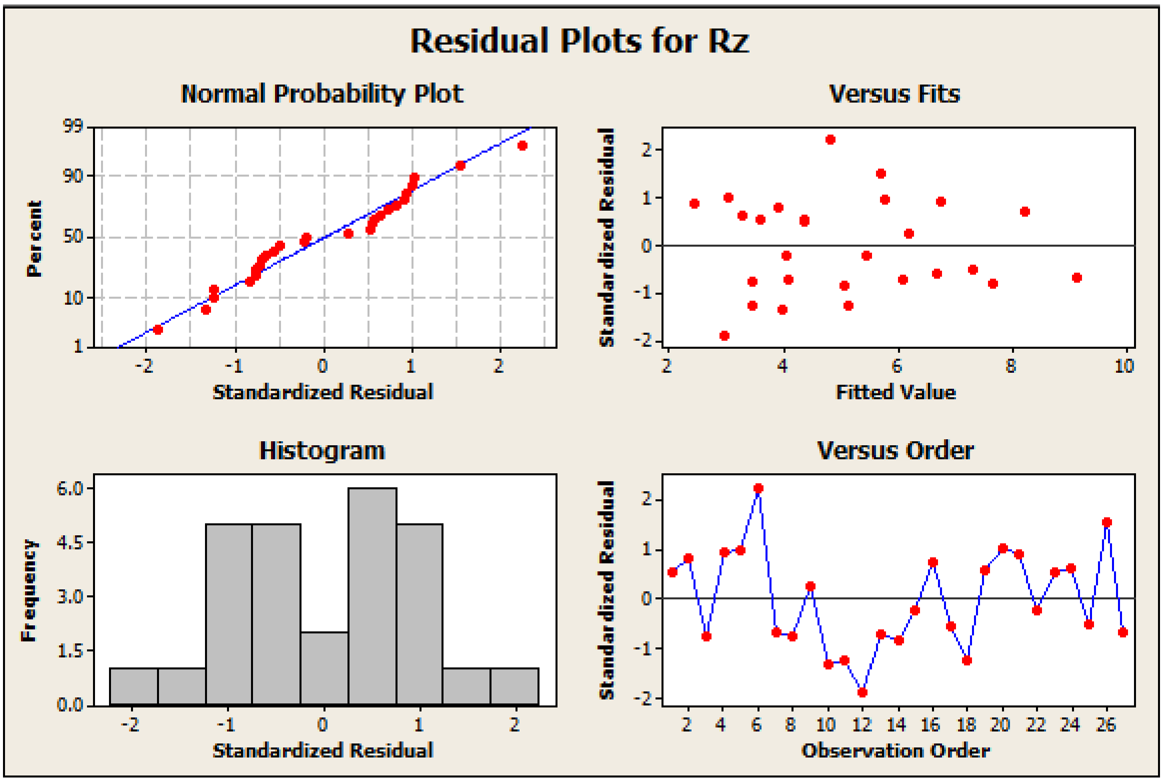


Fig.5.8 Residual plots for surface roughness (Rz)

CHAPTER 6

CONCLUSIONS

6.1 Conclusions

The experimental analysis of surface roughness of EN-24 hardened steel was carried out. It include hard turning of EN-24 hardened steel in dry conditions. EN-24 is an equivalent of AISI 4340 steel. The turning operation was carried out with the help of coated carbide insert. The insert constituted of TiCN and ZrCN coating. After completing the experiments the followings were concluded:

1. Taguchi orthogonal array design was used to evaluate the influence, the input parameters (speed, feed and depth) had on the response or the output parameter which is the surface roughness and the optimal machining conditions were determined to minimize the surface roughness during turning operation.
2. The research finding along with the various mathematical analysis will provide the effective guideline to select favourable parameters for attaining the desired surface roughness during turning operation of EN-24 hardened steel using coated carbide insert.
3. Feed (F), speed (V) and depth (D), all were found to be significant parameters for the workpiece surface roughness, R_a and R_z with P-values of 0.000 except for 0.001 of depth of cut in case of R_z which is also very less than 0.05. Furthermore, among the interactions V×F was found to be the most significant parameter for surface roughness, R_a and R_z with P-values of 0.002 and 0.021 respectively followed by F×D with P-values of 0.017 and 0.034 for R_a and R_z respectively.
4. From the analysis, it was found that, the multilayer coated carbide inserts have performed well and provide us with an optimal operating condition when at a combination of speed of 150 m/min, feed of 0.10 mm/rev and depth of 0.4 mm.
5. The relationship between machining parameters (input parameters i.e., speed, feed and depth) and surface roughness parameters, R_a and R_z are expressed by the linear regression model in the form of correlation equations.

6. The regression models of workpiece surface parameters, R_a and R_z presented high coefficient of determination (R^2 = 0.9144 and 0.8680) which are close to unity explaining 91.44% and 86.80% of the validity in the response (Y variable or the output parameter) that indicates the goodness of fit for the model

6.2 Scope for future work

It is concluded from the experiment that ZrCN coated carbide insert is capable to turn hardened EN-24 workpiece at dry cutting conditions, it is necessary to optimize the process parameters and model the surface roughness for effective hard turning applications and also when lubrication is done during turning operation. This work can have a very simple variation with varying determining parameters and materials used in the tool and the workpiece. So, there is much that can be done in this field.

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